

TOWARDS AN EQUATION OF EVERYTHING IN THE THREE-DIMENSIONAL DYNAMIC QUANTUM VACUUM

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Abstract

An equation of everything in a model of a three-dimensional dynamic quantum vacuum defined by a variable energy density and by a generalized Compton wavelength which provides a unified treatment of microphysics and macrophysics, is introduced. The consequences of this equation in the different regimes and as regards the interpretation of time as numerical order of material change are explored. Finally, a new solution of the paradoxes connected to black hole complementarity and information is proposed.

Keywords: equation of everything, three-dimensional dynamic quantum vacuum, generalized Compton wavelength, path integrals, numerical order of material change, black holes.

1. Introduction

The Holy Graal of theoretical physics lies in the search of a theory encompassing all matter and forces, of a set of equations capable of describing all phenomena that have been observed and, in particular, that provides a synthesis of quantum physics and general relativity and a unified treatment of the four fundamental interactions. Several paths have been developed in order to address these problems, which go from the various approaches of superstring theory to loop quantum gravity to other less known approaches (see, for example, [1-10]).

The search of a theory of everything, if originally seemed to be seen as the consequence of the implementation of a reductionist approach, however, in more recent times, by virtue of the apparent impossibility of incorporating gravity in the context of workable quantum field theories and of recognizing it as a full member of the Standard Model, has assumed a new status, represented by the development of the so-called effective theories [11-21]. According to this line of research, one can make a separation between the scale we are working and the unknown physics regarding the much higher energies, thus arriving to obtain predictions at present energies without making unwarranted assumptions about what occurs at high energies. So, if the present Standard Model is an effective theory which breaks down at the TeV scale, where Higgs self-interactions would otherwise become unnaturally large, general relativity can be perhaps considered as the best example of an effective field theory since it involves very small quantum corrections, overlaps with quantum physics in regions where the latter is relevant and shows no hint of a breakdown before the Planck scale. Thanks to the development of the quantum techniques in the last 30 years, we have today a theory of Quantum General Relativity which treats general relativity, within various limits, as an effective field theory and is defined by a path integral over the dynamical degrees of freedom guided by a local Lagrangian.

The crucial idea of an effective field theory is that the low energy degrees of freedom organize themselves as quantum fields, ruled by a local Lagrangian, in general containing non-renormalizable terms suppressed by powers of a heavy scale, in such a way that one can make predictions without knowledge of the full high energy theory. In this picture, by investigating general relativity as a quantum field theory by means of the tools of effective field theory, in the region of validity of the effective field theory, it can be studied in perturbation theory and the quantum corrections are small, thus making it as the best perturbative theory ever, that leads to relevant lessons for the development of theoretical physics. In particular, in the Core Theory developed by Sean Carroll, which is an effective field theory that contains the well-known Standard Model of particle physics, but also quantum general relativity in the weak-field limit, the equation that underlies all the phenomena of our everyday experience is the following:

$$A = \int_{k < \Lambda} [Dg][DA][D\Psi][D\phi] \exp \left\{ \frac{i}{\hbar} \int d^4x \sqrt{-g} \left(\frac{c^4}{8\pi G} R - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \right. \right. \\ \left. \left. i\bar{\psi}\gamma^\mu D_\mu\psi + |D_\mu\phi|^2 - V(\phi) \right) + (\bar{\psi}_L^i Y_{ij} \phi \psi_R^j + h.c.) + \sum_a \mathcal{O}^{(a)}(\Lambda) \right\} \quad (1)$$

where R is gravity, $F_{\mu\nu}F^{\mu\nu}$ are the gauge fields of strong, weak and electromagnetic interactions, $i\bar{\psi}\gamma^\mu D_\mu\psi$ is the kinetic energy of the fermion fields, $|D_\mu\phi|^2$ is the kinetic energy of the Higgs, $V(\phi)$ is the Higgs potential, $\bar{\psi}_L^i Y_{ij} \phi \psi_R^j$ is the Higgs-fermion interaction, the parameter $k < \Lambda$ is the cutoff in the overall path integral (which is of the order $10^{11} eV$) and the term $\sum_a \mathcal{O}^{(a)}(\Lambda)$ represents an infinite series of higher-order terms, each of which in general will be suppressed by powers of the cutoff, guaranteeing that physical predictions are independent of the cutoff value. According to equation (1), the domain of applicability of the Core Theory – and thus of an effective field theory – corresponds to energy and momenta that are all below the cutoff scale Λ in the sense that in this regime the theory is accurate [20, 21].

Although the dynamics described by effective field theories, such as the one summarized in equation (1) of the Core Theory, are well-defined, quantitative, as well as experimentally tested in a wide variety of contexts, however, it must be emphasized that an essential feature of the structure of effective theories across physics lies in their intrinsic empirical limitations, i.e. the fact that they meet their own predictive failure at some scale. In this regard, the most straightforward realist explanation of this predictive pattern is to consider effective theories to accurately represent limited parts of the world [22].

In this paper, we want to throw new light as regards the problem of the search of an equation of everything which embeds the different regimes of physics, by going beyond the ideas subtending effective field theories and, in particular, by going beyond the equation (1) of Carroll's Core Theory and, at the same time, providing a new key of reading of the processes with respect to the well known reductionist approaches of quantum gravity such as superstring theory and loop quantum gravity. Here, our purpose is to suggest an alternative way to formulate an equation of everything, which is based on a model of a three-dimensional dynamic quantum vacuum (3D DQV), proposed by the author in recent papers [23-32], which postulates the existence of an underlying variable quantum vacuum energy density and, by starting from a peculiar specific form of generalized uncertainty relations, leads to define a universal scale that provides a unified treatment of macroscopic regime of black holes and quantum regime of elementary particles. We will see how the activity of the variable quantum vacuum energy density at this universal scale provide important lessons as regards the foundations and the development of theoretical

physics, which throw new light in the unifying description of the different processes of physics.

The paper is organized as follows. In section 2, we review the fundamental features of the model of the 3D DQV, which go to constitute important ingredients of the equation of everything. In section 3 we formulate our equation of everything in the 3D DQV and we derive its consequences in the different regimes, the dynamics laws for matter and gravity and the laws for the boundary condition of the universe. In section 4, we explore our interpretation of time in the theory of everything of the 3D DQV. In section 5 we suggest new perspectives of solution to some of the paradoxes connected to black holes. Finally, in section 6 we summarize the main results of the paper and we conclude by exploring the perspectives of the approach based on this equation of everything of the 3D DQV as regards the problem of finding a relation between the theory and the experience.

2. The ingredients of the equation of everything in the three-dimensional dynamic quantum vacuum

As regards the challenge of contemporary theoretical physics directed towards a unified description of quantum phenomena and gravity, an important research line that has received attention in the last thirty years is represented by the so-called generalized uncertainty principle, namely the idea that, at the quantum-gravity scale, the Heisenberg uncertainty relations should be modified in order to take into account the existence of a minimal length. Different forms of the generalized uncertainty principle have been explored in different domains, ranging from string theory and loop quantum gravity, to deformed special relativity, black hole physics, non-commutative geometry and asymptotically safe gravity [33-42].

In the model of the 3D DQV, we assume that the geometry of the background is expressed by the following peculiar specific form of generalized uncertainty relations, which are valid at the Planck scale:

$$\Delta x \Delta p \geq \frac{\hbar}{2} \left(1 + \beta l_p^2 \frac{\Delta \rho_{qvE}^2 V^2}{\hbar^2 c^2} \right) \quad (2)$$

In equation (2) $\Delta \rho_{qvE}$ is the variable energy density of the vacuum corresponding to the appearance of a material particle of mass m in a volume V , defined as

$$\Delta \rho_{qvE} \equiv \rho_{pE} - \rho_{qvE} = \frac{mc^2}{V} \quad (3),$$

where

$$\rho_{pE} = \frac{m_p \cdot c^2}{l_p^3} \quad (4)$$

is Planck's energy density (m_p being Planck's mass, c the light speed and l_p Planck's length) intended as the ground state of the 3D DQV, β is a fluctuating dimensionless parameter which expresses the fact that here one deals with quantum vacuum fluctuations, associated with virtual particles, that fix the minimal length scale only on average, $\hbar$ is Planck's reduced constant and the term $\frac{\hbar}{2} \beta l_p^2 \frac{\Delta \rho_{qvE}^2 V^2}{\hbar^2 c^2}$ measures the degree of violations of the Heisenberg uncertainty relations at scales that approach the Planck scale. The generalized uncertainty relations (2) lead to a suggestive unification of the quantum regime of elementary particles and the macroscopic regime of black holes in terms of a generalized Compton wavelength which provides a unified expression for the Compton wavelength and Schwarzschild radius, given by relation

$$R'_C = R'_S = \sqrt{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2} \quad (5)$$

Equation (5) implies that the generalized Compton wavelength (5) tends to the standard value of the Schwarzschild radius for $\frac{\Delta \rho_{qvE} V}{c^2} \gg M_{Pl}$ where M_{Pl} is the Planck mass, while tends to the quantum regime (namely to the standard value of the Compton wavelength associated to an elementary particle) for $\frac{\Delta \rho_{qvE} V}{c^2} \ll M_{Pl}$. The physical meaning of equation (5) is that the origin of elementary particles of the quantum world and of material objects and black holes of macroscopic regime, is represented by elementary objects of the Planck scale, namely sub-Planckian black holes with a size of order of their Compton wavelength, which are generated by the geometrodinamic properties of the variable quantum vacuum energy density ultimately associated to the foam of the virtual particles of the 3D DQV [31, 32].

In the microscopic structure of the 3D DQV defined by the generalized Compton wavelength (5), the activity of the sub-Planckian black holes of the underlying variable energy density generates a deformation of the geometrical properties of the background expressed by a quantum-modified Schwarzschild metric which has the following form

$$ds^2 = F(r) c^2 dt^2 - F(r)^{-1} dr^2 - r^2 d\Omega^2 \quad (6)$$

where

$$F(r) = 1 - \frac{\sqrt{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2}}{4r^2} + \varepsilon \frac{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2}{4r^2} \quad (7)$$

and $d\Omega^2 = d\theta^2 + \sin^2 \theta d\phi^2$ is the metric on the 3-sphere and ε is a dimensionless deformation parameter of the metric that, in analogy to the treatment made in [43], satisfies the constraint $|\varepsilon| \leq 1$. The quantum-modified metric (6) determines corrections in the values of the global deflection angle of light, the total precession of the orbit of a planet, the time dilation and the

gravitational red-shift with respect to the corresponding formulations predicted by standard general relativity, leading to general formulas which allow the standard corresponding general relativistic relations to be recovered under appropriate limits [44].

Moreover, each micro-region of the universe is described by a wave-function Ψ (which is a function of the scale factor a and of the scalar fields φ associated with the quantum vacuum energy density fluctuations as well as the polarization of the vacuum), that satisfies a peculiar form of Wheeler-DeWitt (WDW) equation, intended as an equation of background, a real "equation of everything" where all the possibilities of the physical world are written in timeless form:

$$\ddot{\Psi} + \frac{k \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2} \Delta \rho_{qvE}}{a c^2 \sqrt{a}} \Psi + \omega^2(a) \Psi = 0 \quad (8)$$

In equation (8), one has the following quantities: $\Psi = \frac{\partial \Psi}{\partial a}$, α is the fine-structure constant, ω is the mode frequency linked with the scale factor and, finally, k is an adimensional parameter corresponding to the size of the condensate of virtual sub-particles of the 3D DQV, namely represents a sort of effective parameter of density of the virtual particles of the medium [45]. By invoking the third quantization formalism, the wave function Ψ of the universe satisfying WDW equation (8) is promoted to the role of operator, which can be expressed as

$$\hat{\Phi}_{\pm} = \frac{V \Delta \rho_{qvE}}{\sqrt{2\pi\hbar l_p}} \int d\rho \left(e^{\pm i \frac{V \Delta \rho_{qvE}}{\hbar l_p^2} \varphi} \Psi_{\Delta \rho_{qvE}}(a) \hat{b}_{\Delta \rho_{qvE}} + e^{\mp i \frac{V \Delta \rho_{qvE}}{\hbar l_p^2} \varphi} \Psi_{\Delta \rho_{qvE}}^*(a) \hat{b}_{\Delta \rho_{qvE}}^{\dagger} \right) \quad (9)$$

where $\hat{b}_{\Delta \rho_{qvE}}$ and $\hat{b}_{\Delta \rho_{qvE}}^{\dagger}$ are the annihilation and creation operators which annihilate and create respectively micro-universes, associated with corresponding changes of the quantum vacuum energy density, and satisfy the "quantum Boltzmann statistics" that consists of a q deformation of the commutation relations of the oscillators, given by the following relation:

$$\hat{b}_k \hat{b}_l^{\dagger} - q \hat{b}_l^{\dagger} \hat{b}_k = \delta_{kl} \quad (10)$$

and the cases $q = \pm 1$ correspond to bosons and fermions.

The wave function Ψ of a micro-universe satisfying the generalized WDW equation (7) gives origin to the manifestation of a corresponding particle if the information in a cell of the 3D DQV, that is defined by the following relation:

$$I = \frac{\Lambda}{l_p^2} \quad (11)$$

where

$$A = k \left[\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right] \quad (12)$$

is the area of the cell, satisfies relation $l^3 l_p \approx 10^{-13} \text{ cm}$, namely

$$\frac{k^3}{l_p^3} \left[\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right]^3 \approx 10^{-13} \text{ cm} \quad (13)$$

This means that one can choose opportunely the parameter k defining the size of the condensate of the virtual sub-particles of the medium in order to obtain the appearance of the desired particle of the Standard Model with its usual properties and, therefore, that the chronon scale of ordinary Standard Model particles can be interpreted as the emergence scale of processes of collective organization of opportune condensates of the virtual sub-particles of the 3D DQV which take place at the generalized Compton wavelength.

On the other hand, also the Higgs mass can be seen as the upper emergent manifestation resulting from the activity of the quantum vacuum energy density fluctuations at the generalized Compton wavelength [46]. The Mexican hat potential that in 3D DQV geometry plays the role of the Higgs mechanism is given by relation

$$\begin{aligned} V(\psi) = & \frac{1}{4} \left[\frac{\xi^2}{2\pi} k \omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{-9/2} + \\ & \left[\frac{\xi^2}{2\pi} k \omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{-3/2} \hbar^2 + \\ & \left[\frac{\xi^2}{2\pi} k \omega m |\Psi|^2 \right]^{1/2} \hbar^3 + \frac{1}{4} \left[\frac{\xi^2}{2\pi} k \omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \right. \\ & \left. \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2} \hbar^4 \quad (14) \end{aligned}$$

and the Higgs doublet is

$$\phi = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 \\ 1 \\ k \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2 + \hbar} \end{bmatrix} \quad (15)$$

where $\hbar$ denotes the excitations of the 3D DQV from the vacuum expectation value ε which is related to the rest mass of the W boson as

$$\varepsilon = \frac{\sqrt{2} c^2}{g} M_W \quad (16)$$

As regards the interaction of the Higgs with the gauge bosons, one can express it via the following equation

$$\left| \left(i \frac{g}{2} \sigma_i W_\mu^i + i \frac{g'}{2} B_\mu \right) \Psi \right|^2 = \frac{1}{8} \left[\frac{1}{k \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2}} + \hbar \right]^2 \times$$

$$\left[g^2 (W_\mu^1)^2 + g^2 (W_\mu^2)^2 + (-g W_\mu^3 + g' B_\mu)^2 \right] \quad (17)$$

where g, g' are the gauge couplings. In the light of relation (17), one finds that the masses of the vector bosons are the following:

$$M_W = \frac{g}{2k_W \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2}} \quad (18)$$

and

$$M_Z = \frac{\sqrt{g^2 + g'^2}}{2k_Z \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2}} \quad (19),$$

where k_W is the constant associated to the condensate of virtual sub-particles of the vacuum corresponding to the appearance of a W boson and k_Z is the constant associated to the condensate of virtual sub-particles of the vacuum corresponding to the appearance of a Z boson. In this way, the weak mixing angle expressing the relationship between the masses of W and Z bosons in the Standard Model, in the approach of the 3D DQV becomes

$$\cos \theta_W = \frac{g k_Z}{k_W \sqrt{g^2 + g'^2}} \quad (20).$$

Finally, one can also find a new formulation for the Fermi constant

$$G_F = \frac{\sqrt{2}}{4} k_W^2 \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^3 \quad (21)$$

and here, by taking account of the numerical experimental value of the Fermi constant, one directly obtains the following constraint regarding the electroweak scale:

$$\frac{1}{k \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2}} \sim 246 \text{ GeV} \quad (22).$$

As regards the treatment of the TeV scale of strong interactions, taking account of the results of [32, 46], a spontaneous dynamical scale symmetry breaking can be obtained by considering the mean-field approximated effective Lagrangian of the form

$$\mathcal{L}_{MFA} = ([\partial^\mu S_R]^+ \partial_\mu S_R) - \varepsilon^2 (S_R^+ S_R) - \lambda_C (H^+ H)^2 + N_f (N_f \lambda_S + \lambda_S') f^2 +$$

$$\frac{\lambda_S'}{2} (\phi^a)^2 - 2\lambda_S' \phi^a (S_R^+ t_{ij}^a S_R) \quad (23).$$

In equation (23) s_R is a scalar field depending on the energy fluctuations of the vacuum, $f = (s_R^+ s_R)/N_f$, H is the Higgs doublet field which defined by equation (12), $\phi^a = 2(s_R^+ t_{ij}^a s_R)$ are auxiliary fields with t_{ij}^a generators of the flavour $SU(N_f)$ transformation and $\varepsilon = k\Delta\rho_{qvE}$ is a “constituent” scalar variable quantum vacuum energy of the hidden sector of the strong interactions – which is determined by opportune collective excitations of the virtual particles of the 3D DQV – given by relation

$$\varepsilon^2 = 2(N_f\lambda_S + \lambda_{S'})f - \lambda_{SC}(H^+H) \quad (24).$$

Here, if one sets $\phi^a = 0$ in the mean-field approximation lagrangian, one can obtain the effective potential

$$V_{MPA} = k^2 \frac{M_P^2 c^4}{V^2} (\bar{s}_R^+ \bar{s}_R) + \lambda_C (H^+ H)^2 - N_f (N_f \lambda_S + \lambda_{S'}) f^2 + \frac{N_C N_f k^4 M_P^4 c^8}{32\pi^2 V^4} \ln \frac{M_P^2 c^4}{V^2 \Lambda_C^2} \quad (25)$$

where $\bar{s}_R$ is the background field of the scalar field s_R . The effective potential (25), by applying the dimensional regularization and the $\overline{MS}$ scheme to eliminate a ultraviolet divergence, can be considered as the real mediating entity that is responsible of the spontaneous symmetry breaking occurring at the TeV scale, by leading directly to the following expressions for the changes of the vacuum energy associated to the collective excitations of the virtual particles of the 3D DQV, and the Higgs mass:

$$\langle k^2 \frac{M_P^2 c^4}{V^2} \rangle = \frac{4N_f \lambda_C \lambda_S - N_f \lambda_{SC}^2 + 4\lambda_C \lambda_{S'}}{2\lambda_C} \langle (s_R^+ s_R)/N_f \rangle \quad (26)$$

$$M_h^2 \cong 2N_f \lambda_{SC} \langle (s_R^+ s_R)/N_f \rangle \quad (27)$$

where here a small λ_{SC} is assumed. On the basis of equations (26) and (27), the variable quantum vacuum energy, the scalar field s_R depending on the energy fluctuations of the dissipative vacuum, as well as the scalar couplings λ_{SC} , λ_C , λ_S associated with the vacuum and with the singlet field depending on the quantum vacuum energy density fluctuations, can be considered the ultimate parameters which are responsible of the generation of the action of the Higgs boson in the high-energy regime. In other words, it is the interplay of opportune fluctuations of the energy of the 3D DQV which indeed determines the action of the Higgs boson generating a spontaneous symmetry breaking at the TeV scale.

3. The equation of everything and its predictions in the different regimes

In the light of all the results, mentioned in the previous chapter, of the model of the 3D DQV, as regards the quantum-modified metric associated with the generalized Compton wavelength, the condensate of the virtual sub-particles of the vacuum corresponding to the appearance of the particles of the Standard Model, as well as the interplay of specific fluctuations of the quantum vacuum

energy density mimicking the action of the Higgs boson, one can introduce the following equation of everything in the three-dimensional quantum vacuum model characterized by the unification scale represented by the generalized Compton wavelength:

$$\begin{aligned}
 W = \int [Dg][D\psi][D\Psi][D\phi] \exp \left\{ \frac{i}{\hbar} \int \left(\left[1 - \frac{\sqrt{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}}{r} + \right. \right. \\
 \left. \left. \varepsilon \frac{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}{4r^2} \right] c^2 dt^2 - \left[1 - \frac{\sqrt{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}}{r} + \right. \right. \\
 \left. \left. \varepsilon \frac{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}{4r^2} \right]^{-1} dr^2 - r^2 d\Omega^2 \right) \sqrt{-g} \left(\frac{c^4}{8\pi G} R - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \right. \\
 i\bar{\psi} \gamma^\mu D_\mu \psi + |D_\mu \phi|^2 - \left(\frac{1}{4} \left[\frac{\xi^2}{2\pi} k\omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \right. \right. \\
 \left. \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{-9/2} + \left[\frac{\xi^2}{2\pi} k\omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \right. \\
 \left. \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{-3/2} \hbar^2 + \left[\frac{\xi^2}{2\pi} k\omega m |\Psi|^2 \right]^{1/2} \hbar^3 + \\
 \left. \left. \left. \frac{1}{4} \left[\frac{\xi^2}{2\pi} k\omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2} \hbar^4 \right) \right) + (\bar{\psi}_L^i Y_{ij} \phi \psi_R^j) \right\} \\
 (28).
 \end{aligned}$$

In equation (28) R is the scalar curvature characterizing the region under consideration, g is the gravitational field, $F_{\mu\nu} F^{\mu\nu}$ are the gauge fields of the strong, weak and electromagnetic interactions, $\bar{\psi} \gamma^\mu D_\mu \psi$ is the kinetic energy of the fermion fields, γ^μ are the usual Dirac matrices, $|D_\mu \phi|^2$ is the kinetic energy of the Higgs,

$$\begin{aligned} & \frac{1}{4} \left[\frac{\xi^2}{2\pi} k\omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{-9/2} + \\ & \left[\frac{\xi^2}{2\pi} k\omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{-3/2} \hbar^2 + \\ & \left[\frac{\xi^2}{2\pi} k\omega m |\Psi|^2 \right]^{1/2} \hbar^3 + \frac{1}{4} \left[\frac{\xi^2}{2\pi} k\omega m |\Psi|^2 \right]^{1/2} \left(\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \right. \\ & \left. \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right)^{3/2} \hbar^4 \end{aligned}$$

is the Mexican hat potential playing the role of the Higgs mechanism, $\bar{\psi}_L^i Y_{ij} \phi \psi_R^j$ is the Higgs-fermion interaction, ψ_L^i are left-handed fermion fields, ψ_R^j are right-handed fermion fields, Y_{ij} is the mixed matrix and Ψ is the wave function of each region of the multiverse. This equation expresses the amplitude of transition of the vacuum from one configuration to another configuration, in terms of Feynman's path integrals computed on all the modes in which the fields of the vacuum could evolve. We must point out that the equation of everything (28) allows us to treat processes in a coherent way, both in the quantum gravity regime by considering the universal generalized Compton wavelength (5), and in the peculiar regimes where the generalized Compton wavelength may be approximated with the Schwarzschild radius or with the standard Compton wavelength.

It is interesting to explore how the approach of the 3D DQV based on the equation of everything (28) allows us to face some problems of the Standard Model. As well known, the Standard Model is affected by a hierarchy problem, i.e., in the light of the absence of new-physics signatures at the TeV scale and beyond, the observed Higgs mass appears rather "unnatural" [47], and in current models – such as supersymmetric extensions [48-51], strong dynamics or technicolor models [52, 53] composite Higgs [54-56] and extra dimensions [57-59] – the question of vacuum stability depends on whether the Higgs self-coupling crosses zero or not deep in the ultraviolet and involves a delicate balance of Standard Model parameters, i.e. implies the necessity of a fine-tuning, of choosing very carefully the parameters of new high-scale physics in order to result in the observed low-energy parameters. Instead, we must remark that our approach of the 3D DQV based on the equation of everything (28), in which the elementary constituents are sub-Planckian black holes of the variable energy density defined at the generalized Compton wavelength (5), does not present the hierarchy problem, in the sense that the different scales – such as the value of the Higgs mass – must not be justified by invoking procedures of fine-tuning but rather emerge as a natural consequence of the theory. In the approach based on the equation of everything (28), the different scales naturally emerge

as a consequence of the peculiar Feynman's path integrals present in the computation, and thus of the specific modes in which the fields of the vacuum could evolve.

The equation of everything (28) leads also to directly derive a gravito-electroweak unification scale M_{unif} by starting from the generalized Compton wavelength and therefore as a phenomenon determined by the virtual "sub-Planckian black holes of the variable energy density of the three-dimensional dynamic quantum vacuum", in terms of relation

$$M_{unif} = \frac{1}{2} \left(\frac{3\hbar^2 M_{Pl}^2}{\pi c^2 \left[\left(\frac{\beta \hbar c}{\lambda \rho_{qv} E^V} \right)^2 + \left(\beta t_p^2 \frac{\lambda \rho_{qv} E^V}{\hbar c} \right)^2 \right]} \right)^{1/4} \quad (29).$$

On the basis of the mass unification scale (29), the mass-squared differences of neutrinos determined by fluctuations of the quantum vacuum energy density associated with the virtual "sub-Planckian black holes" of the variable energy density of the 3D DQV, lead to corresponding values of the unification scale for solar and atmospheric neutrinos that turn out to be in good agreement with the results obtained in [60] as well as in other previous theories of electroweak unification [61-63].

On the other hand, in the presence of quantum gravity, namely if the Planck mass is not negligible, we know that in a perturbative approach, when the gauge coupling g of matter inside a $U(1)$ theory tends to zero, a cut-off m_0 , which typically corresponds to the mass of the lightest state in an infinite tower of states, appears, namely

$$g \rightarrow 0 \Rightarrow m_0 \lesssim g M_{Pl} \quad (30).$$

This physics cut-off turns out to be associated to infinite tower of states, such as string or Kaluza-Klein excitations that have to put towards a higher dimension in order to face the issue [64-69]. In the picture of an effective field theory coupled with the gravitational field the presence of a cut-off m_0 turns out to be unfamiliar, in the sense that determines the risk of the gauge interaction becoming weaker than gravity. Now, we must emphasize that, in the approach based on the equation of everything (28), this peculiar problem is not present, in the sense that the cut-off m_0 turns out to be a direct consequence of the theory.

In the model of the 3D DQV based on the equation of everything (28) where the elementary constituents are sub-Planckian black holes with a size of order of the generalized Compton wavelength, we underline that the emergence of gravitation and quantum theory can also be put in an intriguing parallelism with the picture presented by the spectral action principle of Connes' non-commutative geometry, which leads to a pre-quantum, pre-spacetime theory.

Taking account of the results obtained in [70], sub-Planckian black holes can be characterized by a trace dynamic action given by relation

$$S = \hbar \int \frac{d\tau}{t_p} \sum_l Tr \left(\frac{l_p^2}{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2} \right) [\dot{q}_{Bl}^2] \quad (31)$$

where $\dot{q}_{Bl} = D \sqrt{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}$, D being the Dirac bosonic operator, l_p is Planck length, τ is the Connes time parameter that represents a specific feature of non-commutative geometry. The spectral action principle can be also invoked by considering the Yang-Mills gauge fields, in the sense that the gauge field $F_{\mu\nu}$ can be seen as a modification of the Dirac operator: $D \rightarrow D + F_{\mu\nu}$, whose eigenvalues are raised to the status of matrices, that are identified with the configuration variables q_{Bl} of the corresponding Dirac operators $\dot{q}_{Bl}$. Matter (fermionic) degrees of freedom q_{Fl} and $\dot{q}_{Fl}$ can be introduced such that the eigenvalues of these matrices are connected to the classical relativistic action of point particles. The dynamic action (31) of the sub-Planckian black holes leads to directly derive classical space-time and general relativity, since the Dirac operators collapse to (distinct) eigenvalues, and the spectral action principle ensures recovery of the Einstein-Hilbert action coupled to Yang-Mills fields and relativistic point particles, with additional corrections. Those degrees of freedom which are not sufficiently entangled continue to obey the underlying trace dynamics but can be described to a good approximation by conventional quantum field theory on a classical spacetime background.

The equation of everything (28) allows us to obtain the different regimes of physics under opportune constraints without the problems which regard the effective field theories approach. In particular, for $\frac{\Delta \rho_{qvE} V}{c^2} \gg M_{Pl}$ we enter the classical general-relativistic regime, where only the paths corresponding to negligible quantum effects are active for the processes into consideration. In this regime, the amplitude (28) of transition of the vacuum from one configuration to another configuration may be approximated as

$$W_{grav} = \int [Dg][D\psi][D\Psi][D\phi] \exp \left\{ \frac{i}{\hbar} \int \left(1 - \frac{\sqrt{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_P^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}}{r} + \right. \right. \\ \left. \left. \varepsilon \frac{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_P^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}{4r^2} \right) c^2 dt^2 - \left[1 - \frac{\sqrt{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_P^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}}{r} + \right. \right. \\ \left. \left. \varepsilon \frac{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta l_P^2 \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2}{4r^2} \right]^{-1} dr^2 - r^2 d\Omega^2 \right) \sqrt{-g} \left(\frac{c^4}{8\pi G} R - \Lambda \right) \right\} \quad (32)$$

where Λ is the cosmological constant, that here corresponds to peculiar quantum vacuum energy density fluctuations given by relation

$$\rho_{DE} \simeq \frac{35 G c^2}{2 \pi \hbar^4 V} \left(\frac{V}{c^2} \Delta \rho_{qvE}^{DE} \right) \quad (33)$$

and that in our model of 3D DQV emerges as the fundamental origin of the curvature of space-time characteristic of general relativity [23-26, 28, 29].

Instead, for $\frac{\Delta \rho_{qvE} V}{c^2} \ll M_{Pl}$ we are in the quantum regime of elementary particles and, in this context, the low energies of the Standard Model correspond to integrals which have a limit, namely an ultra-violet cut-off. In this regard, in particular, the spontaneous symmetry breaking generating the TeV scale of strong interactions occurs when the potential appearing in (28) tend to the effective potential given by (25), thus leading to the expression (27) for the Higgs mass.

However, in the regime of quantum gravity, one must consider all the contributions, at all energies, in these path integrals, on must consider all the modes in which the fields of the vacuum could evolve. Moreover, it must be emphasized that the limit of the theory for $\beta \rightarrow 0$ coincides with the results of non-relativistic quantum mechanics; instead, as regards the limit $\varepsilon \rightarrow 0$ in the regime $\frac{\Delta \rho_{qvE} V}{c^2} \gg M_{Pl}$ where the generalized Compton wavelength tends to the standard Schwarzschild radius, the results are in good agreement with general relativity, and in the regime $\Delta \rho_{qvE} V \ll M_{Pl} c^2$ where the generalized Compton wavelength tends to the Compton wavelength, one obtains the regime of usual elementary particles of the Standard Model.

As regards dark matter and dark energy, it must be emphasized that here these are not mysterious entities which are extraneous, bizarre with respect to the formalism of the theory but are instead as a natural consequence/complement in the sense that can be seen as the results of peculiar fluctuations of the quantum vacuum energy density.

Finally, it is interesting to observe that, on the basis of its features and its consequences in the different regimes, the equation of everything (28) fits naturally also as an useful tool for cosmology. In this regard, one can provide the dynamics laws for matter and gravity, by considering a partition function of the form:

$$Z = \int Dq e^{\frac{i}{\hbar} W} \quad (34)$$

where q contains both matter and gravity variables, eventually incorporating dark matter as the results of peculiar fluctuations of the quantum vacuum energy density. Moreover, the laws for the boundary condition of the universe can be defined in terms of double path integrals of the form

$$D[q] = \int Dq' \int Dq e^{\frac{i}{\hbar} (W[q] - W[q'])} \rho(q_b, q'_b) \quad (35)$$

where the path integral is doubled to account for the possible mixedness of the boundary condition ρ , which as an analog of the density operator takes as inputs the boundary configurations q_b and q'_b in the double copies.

On the basis of the partition function (34) and taking account of the Quantum Boltzmann Statistics characterizing the micro-universes of the 3D DQV, one finds new keys of explanation of the different features of the parallel universes in a more fundamental picture with respect to superstring theory and eternal inflationary model, in the sense that here the different evolutionary possibilities, such as expansion and contraction, as well as the different values of the cosmological constant of the parallel universes, are directly fixed by (and thus can be seen as the direct consequence of) the different specific behaviours of the elementary energetic fluctuations of the 3D DQV [35]. By considering the following semiclassical approximation of the wave function of the k -universe

$$\Psi_k \approx e^{\pm \frac{i}{\hbar} S_0(a)} Z_k(a, \varphi) \quad (36)$$

with S_0 being the action of the gravitational part alone with no interaction and the positive and negative signs in equation corresponding to the contracting and the expanding branches of Ψ_k , respectively, and by defining

$$\tilde{V}_k(a, \varphi) = V(\varphi) + \frac{\lambda^2(a)}{4\pi^2 a^4} \sin^2\left(\frac{\pi k}{N}\right) \quad (37)$$

where $V(\varphi)$ is a potential of the scalar field, one obtains a Schrödinger-type equation for the partition function associated with the k -universe of the form

$$-i\hbar \frac{\partial}{\partial t} Z_k = \frac{1}{2} \left(\frac{1}{a} \frac{\partial^2}{\partial \varphi^2} + a \tilde{V}_k(a, \varphi) \right) Z_k \quad (38)$$

and the following field equation for the scalar field

$$\ddot{\varphi} + 3 \frac{\dot{a}}{a} \dot{\varphi} + \frac{d\tilde{V}_k}{d\varphi} = 0 \quad (39)$$

where the dots stands for derivative with respect to the Friedmann time t , i.e. $\dot{\varphi} \equiv \frac{d\varphi}{dt}$. As regards the field equation (39), one can remark that, while the classical behaviour of the scalar field remains unaltered with respect the usual

description because the last term in the potential $\tilde{V}_k$, given by equation (37), has no influence upon equation (39), instead, in the quantum regime, the extra term in the potential induces a modification in the vacuum state that has to be accounted for any vacuum decay process of the universe, resulting in the process of bubble formation and in a suggestive construction of the global structure of the 3D DQV.

As a consequence of the different possible behaviours of the quantum vacuum energy density fluctuations as well as of the Quantum Boltzmann Statistics characterizing the micro-universes of the 3D DQV, the process of bubble formation and the global structure of a single universe is very rich, in the sense that small baby universes are created from quantum fluctuations of the background. At small values of the scale factor (i.e. values close to the Planck scale) the fluctuations of the scalar field and the effects of the interaction among the universes are dominant, so the newborn universes are expected to remain in normal modes with a high value of k . In other words, our universe can be seen as a large parent universe propagating in a plasma of baby universes. In this picture, the process of creation of these newborn bubbles can be considered as an eternal process, which gives origin in a cyclic way to new systems of space and matter in dynamic equilibrium.

Moreover, as regards the issue of cosmological constant, as a consequence of the different possible behaviours of the partition function (34) and therefore of the quantum vacuum energy density fluctuations, universes with different values of the cosmological constant are possible. In this regard, on the basis of the results obtained in [71], if a universe was born in a metastable false vacuum state represented by the local minimum of a canonical scalar field describing the current stage of accelerated expansion of the universe (and which can be identified with the density of the dark energy), one can suppose that successively there was a relaxing to the small values of today, as a consequence of the fact that the value of the cosmological constant is characterized by a diminishing during the post-inflationary phase.

4. The interpretation of time

The standard WDW equation as well as relevant research on quantum gravity imply that time, at a fundamental level, cannot be considered a primary physical reality but represents only an emerging feature, i.e. that the ultimate background of physical processes, at a fundamental level, is timeless. Contemporary theoretical physics leads to the result that time has not a fundamental citizenship in physics, pointing towards the so-called "frozen formalism" which apparently tells that nothing should happen in the universe at the ultimate level, therefore generating the problem regarding how one can extract dynamics from a timeless non-dynamical space. In this regard, the two most famous attempts to address the so-called "problem of time" existing in the

literature are Barbour's "no-time interpretation" and Rovelli's thermal time hypothesis [72-83]. Barbour's approach suggests a Machian resolution to the problem of time by replacing time with a reparametrization invariant action that is integrated over an unphysical evolution parameter, called the ephemeris time, that provides a metric-trans-temporal notion of identity between two subsequent configurations, thus implying a complete emergence of time from the dynamics. Rovelli's "thermal time hypothesis", lies in the idea that the familiar notion of time emerges at the thermodynamic level, when one provides an approximate statistical description of a system with a large number of degrees of freedom, that what we call "time" is the thermal time of the statistical state in which the world happens to be, when described in terms of the macroscopic parameters we have chosen, in summary that time is the expression of our ignorance of the full microstate, a reflex of our incomplete knowledge of the state of the world. According to Rovelli's approach, an idealized time is not defined at the fundamental level (at the Planck scale), namely, in the quantum gravity regime, time should be simply forgotten.

In the theory of everything of the 3D DQV, where the elementary constituents are sub-Planckian black holes of the variable energy density and each regime of physical processes is a consequence of the equation of everything (28), one can go a step ahead with respect to Barbour's and Rovelli's theories and provide a unifying re-reading of these theories, in the sense that time exists only as a mathematical quantity measuring the numerical order of events, that, at the fundamental level, is an emergent feature from the deepest processes occurring at the generalized Compton wavelength. In our approach, we consider the possibility that time measured by clocks can be interpreted as a counter function of the number of states regarding the dynamics of the system under consideration, as a phenomenon that derives from the fundamental variable quantum vacuum energy density. We suggest that time is a mathematical quantity emerging from the frequency modes of the 3D DQV associated with the variations of the quantum vacuum energy density with respect to its ground state defined by the Planck energy density (4) at the fundamental scale represented by the generalized Compton wavelength.

In the geometry of the 3D DQV, the entanglement between the clock and the evolving system whose dynamics is studied generates a numerical order of material changes of this system that corresponds to dissipative features of the vacuum near the Planck scale that can be expressed by an opportune dispersion relation of the form

$$\omega^2 = c^2 k^2 - \frac{c^4 \hbar^2}{\Delta \rho_{qve}^2 V^2} k^4 \quad (40)$$

where the wave number k is assimilated just to the inverse of the generalized Compton wavelength (5), yielding

$$\omega^2 = \frac{c^2}{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2} - \frac{c^4 \hbar^2}{\Delta \rho_{qvE}^2 V^2 \left[\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2\right]} \quad (41) [46].$$

The dissipative features of the 3D DQV described by the dispersion relation (41) imply that the states of the clock are ruled by a non-linear Schrödinger equation, a peculiar version of the Gross-Pitaevskij equation of the form

$$i \hbar \frac{\partial \psi}{\partial t} = \frac{-\hbar^2}{2m} \nabla^2 \psi + \frac{a^2}{2\pi} \left(\sqrt{\frac{c^2}{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2} - \frac{c^4 \hbar^2}{\Delta \rho_{qvE}^2 V^2 \left[\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2\right]}} \right) m |\psi|^2 \psi + U \psi \quad (42)$$

where m is the mass of each sub-planckian black hole of the physical vacuum, U is the potential energy relating to the single virtual particle and v is a viscosity coefficient having the dimensions $\frac{\text{length}^2}{\text{time}}$ which can be expressed as $v = \frac{a^2 \omega}{2\pi}$ where a is the scattering length between the virtual particles. As a consequence of the dissipative processes of the vacuum described by the Gross-Pitaevskij equation (42), the time marked by the clock has the physical meaning of numerical order of material change associated with the dynamics of the system under study, that can be associated to the inverse of the frequency defined by the dispersion relation (41), namely

$$t = \frac{1}{\sqrt{\frac{c^2}{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2} - \frac{c^4 \hbar^2}{\Delta \rho_{qvE}^2 V^2 \left[\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2\right]}}} \quad (43)$$

and can be associated to a quantum observable $\hat{\mathcal{T}}$ as follows:

$$\hat{\mathcal{T}}|t\rangle_c = \frac{1}{\sqrt{\frac{c^2}{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2} - \frac{c^4 \hbar^2}{\Delta \rho_{qvE}^2 V^2 \left[\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2\right]}}} |t\rangle_c \quad (44).$$

The physical meaning of equation (44) is just that the entanglement between the evolving system and the clock generates a counter function labelled by the hands of the clock which is linked with the frequency modes of the 3D DQV, namely with the variations of the quantum vacuum energy density, that are ultimately determined by the dissipative features of the vacuum at the generalized Compton wavelength.

Moreover, taking account the results obtained in [84], we assume that the observable $\hat{H}_c$ and the clock's observable $\hat{\mathcal{T}}$ obey the commutation relation

$$[\hat{\mathcal{T}}, \hat{H}_c] = i \hbar \quad (45)$$

which physically means that $\hat{H}_C$ is the generator of displacements in the position of the clock's hands, i.e. that for an infinitesimal displacement dt it follows that $e^{-i\hat{H}_C dt/\hbar} |t\rangle_C = |t + dt\rangle_C$. As a consequence, the state of the evolving system under study Γ when the clock reads t , that is, when the clock is in the state $|t\rangle_C$, is obtained by projecting $|\Psi\rangle$ onto $|t\rangle_C$ and can be denoted as $|\phi(t)\rangle_\Gamma = \langle t|\Psi\rangle$. In this way we obtain:

$$\frac{\partial}{\partial t} |\phi(t)\rangle_\Gamma = \frac{i}{\hbar} \langle t|\hat{H}_C|\Psi\rangle \quad (46)$$

Now, if we refer to Page's and Wothers' conditional probabilities approach (which provides a way to grasp the idea that the passage of time should be identified with correlations inside the system rather than reflecting changes with respect to an external parameter, thus seeming well-suited for application to the problem of time in quantum gravity), the total Hamiltonian of the composite system evolving system + clock can be expressed as

$$\hat{H} = \hat{H}_C \otimes \hat{\mathbb{I}}_\Gamma + \hat{\mathbb{I}}_C \otimes \hat{H}_\Gamma \quad (47)$$

namely one has $\hat{H}_C \otimes \hat{\mathbb{I}}_\Gamma = \hat{H} - \hat{\mathbb{I}}_C \otimes \hat{H}_\Gamma$ and $\hat{H}|\Psi\rangle = 0$. Therefore, after some algebra, one obtains

$$\begin{aligned} \frac{\partial}{\partial t} |\phi(t)\rangle_\Gamma &= \frac{i}{\hbar} \langle t|\hat{H} - \hat{\mathbb{I}}_C \otimes \hat{H}_\Gamma|\Psi\rangle = \\ &= \frac{-i}{\hbar} \langle t|\hat{\mathbb{I}}_C \otimes \hat{H}_\Gamma|\Psi\rangle = \\ &= \frac{-i}{\hbar} \hat{H}_\Gamma \langle t|\Psi\rangle = \\ &= \frac{-i}{\hbar} \hat{H}_\Gamma |\phi(t)\rangle_\Gamma \quad (48) \end{aligned}$$

namely

$$i\hbar \frac{d}{dt} |\phi(t)\rangle_\Gamma = \hat{H}_\Gamma |\phi(t)\rangle_\Gamma \quad (49)$$

which is the usual Schrödinger equation for the state of the evolving system. Thus, in the model of the 3D DQV where time is a measure of the numerical order of material change associated with dissipative features of the vacuum at the generalized Compton wavelength, by substituting (43) inside equation (49), the Schrödinger equation (49) reads

$$i\hbar \frac{d}{dt} |\phi(t)\rangle_\Gamma = \left(\frac{\hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \Delta \rho_{qvE}^2 V^2 \left[\left(\frac{\hbar c}{\Delta \rho_{qvE} V} \right)^2 + \left(\beta \frac{\Delta \rho_{qvE} V}{\hbar c} \right)^2 \right] |\phi(t)\rangle_\Gamma = \hat{H}_\Gamma |\phi(t)\rangle_\Gamma \quad (50)$$

Equation (50) can be considered as the "timeless" version of the Schrödinger equation in the 3D DQV.

5. Towards new solutions of the paradoxes of black hole complementarity

In the model of the 3D DQV, the fundamental background of processes is represented by elementary objects of the Planck scale, namely sub-Planckian black holes with a size of order of their Compton wavelength that are generated by the geometrodynamical properties of the variable quantum vacuum energy density ultimately associated to the foam of the virtual particles of the vacuum. In this picture, all black holes have an ultimate quantum nature and each subatomic particle can be seen as something similar to a black hole. On the other hand, in the Elementary Cycles Theory developed in some recent papers [85, 86], which posits a unified formulation of relativistic and quantum physics as well as a fully geometrodynamical formulation of gauge interactions, every isolated elementary constituent of nature is characterized by a persistent intrinsic Compton periodicity $T_C = \frac{h}{Mc^2}$, where M is the mass of the particle. Therefore, on the basis of these results, it seems legitimate to consider the possibility that sub-Planckian black holes of the variable quantum vacuum energy density are characterized by a cyclic intrinsic Compton periodicity, which thus emerges as the fundamental connecting element between the particle aspect and the black hole aspect of these elementary objects. On the basis of the treatment made in chapter 4, in our approach, we can consider that the ultimate intrinsic Compton periodicity of the sub-planckian black holes of the variable quantum vacuum energy density is ultimately associated with the dissipative features of the vacuum at the generalized Compton wavelength and expressed by equation (43).

As regards the physics of black holes, quantum mechanics and general relativity have generated relevant conflicts that yielded the two famous paradoxes represented by the black hole information paradox and firewall paradox. On the basis of the Hawking idea of evaporation of semi-classical black holes, the problem is originated of whether the quantum information contained in the matter that collapsed to form the black hole is destroyed and lost forever. The study of the evolution of gravitational collapse through classical models turns out to be deeply unsatisfactory. If at the beginning of the collapse one deals with the formation of a naked singularity [87] then, by considering a semi-classical treatment of the radiation (assuming the validity of effective field theory), from the singularity it is not clear what the final fate of such a collapse is: either the collapsing star will dissipate entirely or a remnant will attempt to generate a covered singularity. Instead, if at the beginning of the collapse one has a covered singularity and the formation of an event horizon then, as Hawking pointed out [88, 89], the semi-classical theory would yield thermal radiation from the point of view of the observer who remains outside the black hole provided that the freely falling observer detects nothing unusual

while crossing the horizon. The semi-classical analysis would seem to suggest that information is lost if the black hole evaporates completely.

On the other hand, the Hawking radiation carrying information was reconciled with the equivalence principle in general relativity by means of the concept of black hole complementarity [90, 91], according to which a freely falling observer crossing the horizon would detect nothing out of the ordinary, while a fixed observer would detect a significant feature known as the "stretched horizon." According to the Susskind and Thorlacius model, an observer who falls into a black hole after extracting information from the Hawking radiation would not be able to detect the same information inside the black hole before reaching the spacelike singularity, considering that information absorbed by the black hole can be reconstructed after the Page time [92, 93]. Instead, Hayden and Preskill [94] suggested that, if information is thrown into a black hole after the Page time, it can still be recovered after the so-called scrambling time, which is typically less than the Page time, thus evading the duplication of information.

Now, in this chapter, we want to show how the model of the 3D DQV based on the equation of everything (28) and thus on the sub-planckian black holes of the variable quantum vacuum energy density defined by the intrinsic periodicity (43) associated with the dissipative features of the vacuum at the generalized Compton wavelength, suggests new perspectives of solution to the paradoxes connected with the physics of black holes. In particular, here the key point is that the wave function of each micro-universe associated with peculiar path integrals that appear in the equation of everything (28) and the consequent interpretation of time as a sequential numerical order of material change emerging from the frequency modes of the 3D DQV associated with the variations of the quantum vacuum energy density, allow us to avoid the paradoxes connected with the simultaneous consideration of the three fundamental assumptions underlying black hole complementarity invoked by Almheiri et. al. (AMPS) [95], i.e.:

1. Hawking radiation is pure;
2. Effective field theory is valid outside a stretched horizon;
3. infalling observers encounter nothing unusual as they cross the horizon.

In the light of Hawking's results [96], the action of the horizon as a "firewall" proposed by Almheiri violates the equivalence principle and breaks the CPT invariance of quantum gravity. In this way, Hawking suggested the idea that no real event horizon is formed and that somehow collapse does not continue beyond an apparent horizon. Recently, Vaz developed the Hawking idea of the apparent horizon as final result of the gravitational collapse by considering a quantum gravitational model of dust collapse [97], which implies that a continued collapse towards a singularity can only be obtained if one combines two independent and entire solutions of the Wheeler-DeWitt equation. By developing a quantum approach to the spherical collapse of inhomogeneous dust in AdS black holes of dimension $d=n+2$, that is described

by the Lemaitre-Bondi-Tolman family of metrics, Vaz found two independent solutions of Wheeler-DeWitt equation in terms of shell wave functions:

$$\psi_l = \psi_l^{(1)} + A_l \psi_l^{(2)} \quad (51)$$

where $\psi_l^{(1)}$ represents dust shells condensing to the apparent horizon on both sides of it and $\psi_l^{(2)}$ represents dust shells that move away from the apparent horizon on either side of it where the exterior, outgoing wave is suppressed by the Boltzmann factor at the Hawking temperature for the shell, and in this picture the AMPS firewall paradox is avoided if A_l tends to zero, thus making $\psi_l^{(1)}$ the complete description of the quantum collapse till the apparent horizon.

Now, in our model of 3D DQV ruled by the generalized Compton wavelength and by the equation of everything (28), we are able to provide an alternative solution to the paradoxes connected to the black hole complementarity. In our approach, the specific active path integrals in the equation of everything (28) as well as the idea of time, and thus of the intrinsic periodicity of the sub-Planckian black holes of the variable energy density of the 3D DQV, acting as numerical order of material change expressed by equation (43), imply that the three fundamental assumptions underlying black hole complementarity are not necessarily incompatible: the final result of the gravitational collapse is an extremely compact quantum object that is held up not by any degeneracy pressure but by quantum gravity processes in the same way that ordinary atoms are sustained by quantum mechanics. More precisely, we deal here with the formation of compact quantum objects as a consequence of the dissipative features of the vacuum at the generalized Compton wavelength.

Here, the standard Wheeler-DeWitt equation is replaced by the equation of background (8) whose general solutions are the wave functions (9) and these wave functions correspond to definite active path integrals in the equation of everything (28). As a consequence, the gravitational collapse characterizing the physics of black holes can be described by means of opportune active path integrals deriving from the equation of everything (28). The active path integrals describing the gravitational collapse of black holes correspond to a lattice of collapsing dust shells, namely micro-universes that, by indicating

$$\sqrt{\frac{c^2}{\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2} - \frac{c^* \hbar^2}{\Delta \rho_{qvE}^2 V^2 \left[\left(\frac{\beta \hbar c}{\Delta \rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qvE} V}{\hbar c}\right)^2\right]}} = \xi, \text{ are defined}$$

by the following wave functions

$$\Psi_{\pm} = \begin{cases} \frac{\sqrt{\Delta \rho_{qvE}}}{\sqrt{2\pi\hbar l_p}} e^{iEt} \int d\rho \left(e^{i\frac{\sqrt{\Delta \rho_{qvE}}}{\hbar l_p} \rho} \Psi_{\Delta \rho_{qvE}}(a) \hat{b}_{\Delta \rho_{qvE}} + e^{i\frac{\sqrt{\Delta \rho_{qvE}}}{\hbar l_p} \rho} \Psi_{\Delta \rho_{qvE}}^*(a) \hat{b}_{\Delta \rho_{qvE}}^\dagger \right) \\ \frac{\sqrt{\Delta \rho_{qvE}}}{\sqrt{2\pi\hbar l_p}} e^{iEt} \left(d - \frac{r}{\hbar \hbar} \right) \int d\rho \left(e^{i\frac{\sqrt{\Delta \rho_{qvE}}}{\hbar l_p} \rho} \Psi_{\Delta \rho_{qvE}}(a) \hat{b}_{\Delta \rho_{qvE}} + e^{i\frac{\sqrt{\Delta \rho_{qvE}}}{\hbar l_p} \rho} \Psi_{\Delta \rho_{qvE}}^*(a) \hat{b}_{\Delta \rho_{qvE}}^\dagger \right) \end{cases} \quad (52)$$

where g_h is the surface gravity at the apparent horizon and d is an opportune parameter $d = d(\Delta\rho_{qvE})$ that depends of the variable energy density corresponding to the formation of the shells. The physical meaning of equation (52) is simple: the micro-universes described by equation (52) represent dust shells condensing to the apparent horizon. These shells have bound states of energy that can be determined by considering the following potential of interaction between the fluctuations of the quantum vacuum energy density and the quantum compact object

$$V(r) = -G \frac{\Delta\rho_{qvE} V m}{2 R c^2} \quad (53)$$

where m is the mass of the dark compact object and R is the radius of the spherical massive shell. In analogy to what happens in the hydrogen atom, on the basis of the potential of interaction (53), one obtains the following bound states of energy of the dust shells:

$$E_n = -\frac{1}{n^2} \frac{G^2 m^3 \Delta\rho_{qvE}^2 V^2}{2 \hbar^2 c^4} \quad (54).$$

The energy spectrum (54) leads to the following mass spectrum of the shells:

$$m_n = \frac{2}{n^2} \frac{G^2 \Delta\rho_{qvE}^4 V^4}{\hbar^2 c^4} \quad (55)$$

The position of the physical quantum shells cannot be exactly localized but can be defined through an average radius expressed by relation

$$\langle R_n \rangle = \frac{3}{2} \frac{m_n c^2}{\Delta\rho_{qvE} V} \sqrt{\left(\frac{\beta \hbar c}{\Delta\rho_{qvE} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c} \right)^2} \quad (56)$$

Now, by following [98], we can compute the minimum value of the shells in Planck units as the difference between the volume of the sphere having radius $\langle R_n \rangle + \frac{1}{2} l_p$ and the volume of the sphere having radius $\langle R_n \rangle - \frac{1}{2} l_p$:

$$V_{min} = \frac{4}{3} \pi \left[\left(\langle R_n \rangle + \frac{1}{2} l_p \right)^3 - \left(\langle R_n \rangle - \frac{1}{2} l_p \right)^3 \right] = \frac{4}{3} \pi \left[3 \langle R_n \rangle^2 l_p + \frac{1}{4} l_p^3 \right] = 4 \pi \langle R_n \rangle^2 l_p + \frac{\pi}{3} l_p^3 \quad (57).$$

Therefore, taking account of the mass spectrum (55), one finds the following expression for the maximum value of the density of the shells:

$$\sigma_{max} = \frac{2 G^2 \Delta\rho_{qvE}^4 V^4}{n^2 \hbar^2 c^4 \left(4 \pi \langle R_n \rangle^2 l_p + \frac{\pi}{3} l_p^3 \right)} \quad (58)$$

which shows that the maximum density is decreasing with increasing of the quantum number n of the shells, as one intuitively expects.

The physical meaning of the approach based on equations (52)-(58) is that, in the light of the active path integrals appearing in the equation of everything (28) and the consequent role of time as numerical order of material change emerging from the dissipative features of the 3D DQV at the generalized Compton wavelength, each shell will condense to the apparent horizon and will not undergo further collapse, namely there is no tunneling into the exterior and no firewall. On the basis of the wave functions (52) of the collapsing dust shells,

the AMPS paradox is directly avoided without further assumptions, in the sense that the paradox connected to the black hole complementarity are not present in the wave functions (52). If the gravitational collapse is described by the wave function (52), the dissipative features of the 3D DQV at the generalized Compton wavelength determine the absence of thermal radiation outside and the presence of a thermal Unruh radiation inside the apparent horizon, therefore implying the non existence of a continuous collapse to a central singularity, in the sense that the collapse would terminate at the apparent horizon, and this result turns out to be in good agreement with the original Hawking proposal [96, 97].

Moreover, as a result of the formation of the apparent horizon determined by the dissipative features of the 3D DQV at the generalized Compton wavelength, the interior spacetime of the black hole emerges as an effective description of a given exterior time in the sense that the apparent horizon indeed produces an entanglement between the information inside the black hole and the information outside the black hole. In this way, the entanglement produced by the apparent horizon leads to the generation of an effective time evolution foliating the interior region that is different from the more fundamental, exterior time evolution, which foliates only the spacetime region outside the horizon. In other words, we can say that the action of the specific path integrals of equation (28) and the consequent of time as numerical order of material change generated by the dissipative features of the vacuum at the generalized Compton wavelength leads to the result that any information in the effective interior is encoded in the modes outside the horizon. As a consequence, the evolution of the system after the formation of the apparent horizon can be seen as a perspective effect owed to the dissipative features of the vacuum at the generalized Compton wavelength, that indeed generate the connection between the information contained in the effective interior of the black hole and the modes outside the apparent horizon. The surface of the apparent horizon, in the light of the dissipative features of the 3D DQV at the generalized Compton wavelength, acts as a sort of entanglement island, implying that some information about the interior might be detectable on the surface of the apparent horizon, where pairs of virtual particles jump in and out of existence in such a way that, if one of these quantum entangled pairs is split up by the apparent horizon and will be held in the black hole, then the other will fly out as Hawking radiation. The entanglement effect determined into the surface of the apparent horizon associated with the processes of collapsing dust shells by the dissipative features of the vacuum at the generalized Compton wavelength, can therefore provide a new key of reading, at a deeper level, of the results recently obtained by Bousso and Penington, regarding the existence of entanglement surfaces that exist slightly outside the event horizon and that, for a supermassive black hole, could extend as much as an atom's length [99].

On the other hand, the entanglement effect between interior and exterior emerging from the peculiar path integrals of the equation of everything (28) that lead to the lattice of collapsing dust shells, can be also seen as a direct consequence of the action of the quantum Boltzmann statistics satisfied by the creation and annihilation operators appearing in the wave functions (52) that describe the gravitational collapse of the quantum shells till the apparent horizon. Moreover, by following [100], the entanglement effect between interior information and exterior modes can be associated with the action of the area of the apparent horizon – expressed in terms of opportune condensates of elementary grains having the size of the generalized Compton wavelength – as a coarse-grained entropy:

$$S_{coarse} = \frac{k \left[\left(\frac{\beta \hbar c}{\Delta \rho_{qv} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qv} V}{\hbar c} \right)^2 \right]}{4 G \hbar} \quad (59)$$

where k is an opportune parameter characterizing the number of grains constituting the surface of the apparent horizon. On the basis of equation (59), the area of the apparent horizon can be considered as the maximum boundary entropy that is compatible with the geometry of its exterior, making a holographic connection between interior information and exterior information in terms of a set of independent qubits, one per elementary area corresponding to a generalized Compton wavelength.

Because of the origin of time as numerical order of material change, and thus of the intrinsic periodicity of the sub-Planckian black holes of the variable energy density of the 3D DQV, from the dissipative features of the 3D DQV at the generalized Compton wavelength and the consequent processes of entanglement between interior information and exterior information of the apparent horizon, physics characterizing the black hole interior can be associated to a perspective effect, i.e. an effective theory regarding a spacetime region K_{t_x} containing a portion of the

$$\text{zone } k \sqrt{\left(\frac{\beta \hbar c}{\Delta \rho_{qv} V} \right)^2 + \left(\beta l_p^2 \frac{\Delta \rho_{qv} V}{\hbar c} \right)^2} < r < r_z \text{ where } r_z \text{ is the location}$$

of the outer edge of the near black-hole region inside the barrier of the effective gravitational potential generated by the black hole, only up to a time

$$T_{t_x} = t_x + 2 \frac{r_+}{c} \ln \frac{r_+}{r_-} \quad (60)$$

where r_+ is the radius of the apparent horizon of the black hole corresponding to the time t_x . This means that, as regards the interior of the black hole, the physics characterizing the interior portion of K_{t_x} should be viewed as occurring in the time frame

$$t_x < t < T_{t_x} \quad (61)$$

The action of the dissipative features of the 3D DQV at the generalized Compton wavelength, that generate the entanglement between interior

information and exterior information of the black hole, rearranges correlations between the degrees of freedom associated with the time slices in (61) in such a way that they can be interpreted as originating from the infalling time evolution generated by an opportune operator without involving a further exterior time evolution. Moreover, we must emphasize that, in the exterior description, by virtue of the perspective effect determined by the dissipative features of the vacuum, ultimately derived from the entanglement interaction between interior and exterior produced by the apparent horizon, the physics which an interior observer experiences at a given spacetime point x must have already happened before the evaporation of the black hole. Thus, whatever the detector does to the final state Hawking radiation, it cannot affect their experience at x nor events occurring in its future.

By following [101], one can also extend the analysis to the case in which one deals with operators before the black hole is fully evaporated, by considering an infalling observer who reaches the apparent horizon in correspondence to some exterior time t_f . While the experience of the observer shortly after crossing the horizon is described by the effective theory of the interior corresponding to t_f , this does not necessarily mean that all the experiences of this observer are described in this effective theory. For example, the observer may accelerate toward the horizon right after they cross it, eventually leaving the region K_{t_f} generating the entanglement perspective effect which connects the information contained in the effective interior of the black hole and the modes outside the apparent horizon. In this case, the minimum numerical order needed by outside observers in order to extract quantum information from the black hole after an infalling observer has been absorbed into the apparent horizon is given by relation

$$t_{scr} = 4 \frac{r_+}{c} \ln \frac{r_+ \xi}{c} \quad (62)$$

that can be defined as the "scrambling time" of black holes in the model of the sub-Planckian black holes of the variable energy density of the 3D DQV. So, the experience of the infallen observer should be viewed as fully completed by the time

$$t_{comp} = t_f + t_{scr} \quad (63)$$

in the exterior description. The experience of the infalling observer can be associated to the time (63) in the sense that the late trajectory of the observer is fully contained in the effective theory associated with the time

$$t_f' = t_f + 2 \frac{r_+}{c} \ln \frac{r_+ \xi}{c} \quad (64)$$

even in the worst case that the observer starts moving outward at the speed of light crossing the mathematical apparent horizon. On the basis of the argument that led to equation (61), any experience of the observer in the interior must have been associated to the time

$$T_{t_f'} = t_f + t_{scr} \quad (65).$$

On the other hand, if one uses the general argument provided in [102], one can say that the information about an object that fell into the black hole at t_f emerges in Hawking radiation only after $t_f + t_{scr}$ as a consequence of the perspective effect, and therefore of the entanglement between interior and exterior determined by the dissipative features of the vacuum. Therefore, as a consequence of the action of the scrambling time intended as a numerical order of material change associated with the dissipative features of the vacuum at the generalized Compton wavelength, it follows that any operation on Hawking radiation — even if it is performed before the time of evaporation, and no matter how complex it is — cannot affect the experience of an observer in the interior. This conclusion is valid even if we extract radiation from the Hawking cloud in the zone around the black hole [103, 104].

The treatment made in this chapter leads to the result that the black hole's singularity cannot be considered a primary physical reality [105]. From an exterior perspective, an object does not immediately thermalize when it encounters the stretched apparent horizon. Instead, it manifests as a distinct excitation on the horizon for some duration in the form of a perspective effect generated by the dissipative features of the vacuum at the generalized Compton wavelength. Over the scrambling time, t_{scr} , this excitation will gradually dissipate into the horizon. During this period, the dissipation process has an effective description as an object traversing the near-empty interior of the black hole. After the object's excitation is fully integrated into the apparent horizon, the perspective effect associated with the dissipation processes of the vacuum and the corresponding effective theory that describes the connection between the information contained in the effective interior of the black hole and the modes outside the apparent horizon, does not hold anymore.

Because of the features of the black hole evolution which involve collapsing dust shells which terminate at the apparent horizon as a consequence of the dissipative features of the 3D DQV at the generalized Compton wavelength, an exterior observer cannot retrieve information about an object which crossed the apparent horizon at an earlier time. Thus, in this picture, there is no problem of cloning if the observer jumps into the horizon. In other words, an observer cannot obtain a second copy of the information and the no-cloning theorem is naturally saved as a consequence of the entanglement action of the apparent horizon between the information contained in the effective interior of the black hole and the modes outside the apparent horizon. In particular, by substituting the scrambling time (61) inside the generalized energy-time uncertainty relation

$$\Delta E \Delta t \geq \frac{\hbar}{2} \left(1 + \beta l_p^2 \frac{\Delta \rho_{QVE}^2 V^2}{\hbar^2 c^2} \right) \quad (66),$$

the duplication of quantum information is avoided (and therefore the information cloning is evaded) if one deals with a scale of energy

$$\Delta E \gg \frac{\hbar c}{8\pi r_+ \ln \frac{r_+}{c}} \left(1 + \beta l_p^2 \frac{\Delta \rho_{QVE}^2 V^2}{\hbar^2 c^2} \right) \quad (67)$$

We underline here that the result (66) turns out to be compatible with the treatment in [106], if the mass of the black hole satisfies relation

$$Mc = \frac{\hbar}{8\pi r_+ \ln \frac{r_+}{c}} \left(1 + \beta l_p^2 \frac{\Delta \rho_{QVE}^2 V^2}{\hbar^2 c^2} \right) \quad (68)$$

In summary, on the basis of equations (67) and (68), we can conclude that the cloning of information is avoided if one deals with a scale of energy that exceeds the quantity $\frac{\hbar c}{8\pi r_+ \ln \frac{r_+}{c}} \left(1 + \beta l_p^2 \frac{\Delta \rho_{QVE}^2 V^2}{\hbar^2 c^2} \right)$ and this occurs when the scrambling time (62) is sufficiently large.

In the Susskind and Maldacena ER=EPR approach, the black hole could connect to all the particles of Hawking radiation through a virtual wormhole, and each Hawking radiation particle would act as the entrance to the wormhole as well as a large space-time region like the inside of a black hole can be composed of a large number of entangled wormholes, implying that the information can get out of the black hole without causing contradiction of quantum entanglement or opening the firewall [107]. Now, in our approach of 3D DQV ruled by the equation of everything (28), where there is no firewall and no primary singularity, one can go beyond the Susskind-Maldacena ER=EPR approach. The intrinsic periodicity of the sub-Planckian black holes of the variable energy density of the 3D DQV acting as numerical order of material change in the form of equation (43) and generated by the dissipative features of the vacuum at the generalized Compton wavelength, implies that the interior of a black hole emerges as a way of reorganizing the degrees of freedom participating in the transient phenomenon of an infalling object dissipating into the apparent horizon. As a consequence of the entanglement action of the surface of the apparent horizon in generating the connection between the information contained in the effective interior of the black hole and the modes outside the apparent horizon, no operation performed on Hawking radiation, however complex, can affect the experience of an infalling observer. Rather, reconstructions of interior operators from Hawking radiation should be interpreted as acting on a historical record of the effective interior, by means of its connection to the information outside the apparent horizon. While in the effective global picture the interior operators appear spacelike separated from the exterior operators used for reconstruction, in the fundamental picture of the 3D DQV ruled by the generalized Compton wavelength and by the equation of everything (28), they are timelike related as a consequence of the dissipative features of the modes of the vacuum, that give origin to the perspective entanglement effect generating the connection between the information contained in the effective interior of the black hole and the modes outside the apparent horizon.

Finally, we emphasize that, in these processes of collapsing dust shells towards an apparent horizon, the transition to extremely compact quantum objects, ruled by quantum gravity, can be considered as the creation of baby-universes which will separate from a plasma of large parent universes. In this regard, by assuming that the end of the black hole evaporation is associated to a mild singularity, the black hole interior can be seen as a closed universe that is separated from the ambient space describing the exterior of the black hole, compatibly with the interpretation provided in [108], according to which, after the black hole evaporates, its microscopic information is encoded in the states of the baby universes arising in the system of replicated black holes associated with the plasma of large parent universes.

6. Conclusions

In the light of the treatment developed in this paper, the model based on the equation of everything of the 3D DQV (28), that provides the transition amplitude of the vacuum from one configuration to another in terms of Feynman path integrals calculated over all the ways in which the fields of the vacuum could evolve, has the merit to achieve significant results:

- it allows the processes to be treated coherently, both in the regime of quantum gravity (in which the universal generalized Compton relation (5) is considered), and in the particular regimes in which (5) can be approximated by the Schwarzschild radius or by the standard Compton wavelength;
- it avoids the hierarchy problem of the Standard Model, in the sense that the different scales do not require fine-tuning but emerge as a general consequence of the theory, as a consequence of the specific active path integrals;
- it allows us to obtain the different regimes of physics avoiding the problems that are present in effective field theories, under appropriate conditions on the variable quantum vacuum energy density;
- it naturally adapts to cosmology, providing new explanation keys for the different features of parallel universes in a more fundamental framework with respect to superstring theory and eternal inflation, in the sense that the different evolutionary possibilities are fixed by the different specific behaviors of elementary energy fluctuations of the quantum vacuum (in the picture of a the semiclassical approximation (35) of the wave function of the generic universe dependent on the partition function (34) which itself ultimately depends on the transition amplitude of the vacuum, i.e. on the equation of everything (28));

- it allows time to be obtained as the numerical order of the movement associated with the dissipative features of the vacuum generated the variable energy density of the vacuum (on the basis of equation (43)).

On the other hand, the approach of time as a mathematical parameter measuring the numerical order of material change that ultimately originates from the dissipative features of the vacuum at the generalized Compton wavelength, leads to important perspectives as regards the issue of the complementarity of the black holes. The three fundamental assumptions invoked by Almheiri et. al. in [95], i.e.:

1. Hawking radiation is pure;
2. Effective field theory is valid outside a stretched horizon;
3. infalling observers encounter nothing unusual as they cross the horizon

are not necessarily incompatible, in the sense that in our model one deals with a lattice of collapsing dust shells, namely micro-universes and each of these shells will condense to an apparent horizon and will not undergo further collapse, and this implies that, in the physics of the black holes predicted by our theory of everything, the ideas of tunnelling into the exterior and firewall can be naturally avoided. The dissipative features of the 3D DQV at the generalized Compton wavelength determine an entanglement action of the surface of the apparent horizon that generates a connection between the information contained in the effective interior of the black hole and the modes outside the apparent horizon, leading to the result that any information in the effective interior is encoded in the modes outside the horizon. In this picture, the evolution of the system after the formation of the apparent horizon can be seen as a perspective entanglement effect owed to the dissipative features of the vacuum at the generalized Compton wavelength, where correlations between the degrees of freedom associated with the time interval (61) are rearranged in such a way that they can be interpreted as originating from the infalling time evolution generated by an opportune operator without involving a further exterior time evolution. The evolution of the collapsing dust shells which terminate at the apparent horizon as a consequence of the dissipative features of the 3D DQV at the generalized Compton wavelength, implies that an exterior observer cannot retrieve information about an object which crossed the apparent horizon at an earlier time and, therefore, here the no-cloning theorem is naturally saved.

The next issue to be addressed regards the search for a relation between the equation of everything (28) of the 3D DQV model and experience. In this regard, despite the difficulties regarding the selection of the active stories in the path integration, that clarify the relation of the equation of everything (28) with experience, by following [60, 109], one can define the relative probability for some experience in the form of conditional probabilities $p(e_i/c)$ where c is a physical condition (that could be the transient physical configuration of a human

being) that enables a set of possible experiences $\{e_i\}_i$, so being relevant for what the observer experiences next, that is expressed by relation

$$p(e_i/c) = N \int_{e_i, c} Dq' \int_{e_i, c} Dq e^{i(W[q]-W[q'])} \rho(q_b, q'_b) \quad (69)$$

In equation (69) $W[q]$ and $W[q']$ are the amplitudes of transition of the vacuum from one configuration to another configuration – given in general by equation (28) – corresponding to two different matter and gravity variables, the subscripts e_i, c indicate that, in both branches of the double path integral, we select physical configurations compatible with the condition c and the experience e_i while the normalization constant N is fixed by requiring $\sum_i p(e_i/c) = 1$. On the basis of the conditional probabilities (69), the perspective is opened that, if one being has a given experience e_i with condition c , everywhere else one deals with matter and gravity path integral configurations that coexist in superposition and considerations of other beings' experiences are motivated by the content of the experiences of the first being, in other words no consideration of other beings is required to account for the experiences of one being. Nonetheless, despite the germinal aspects as regards the relation between this theory and experience, the considerations made in this paper can be considered an interesting starting-point towards a new way to formulate an equation of everything in the picture of path integrals, in the light of the relevant unifying results regarding different regimes.

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